Conceptual Design of a Geostationary Radar for Monitoring Hurricanes

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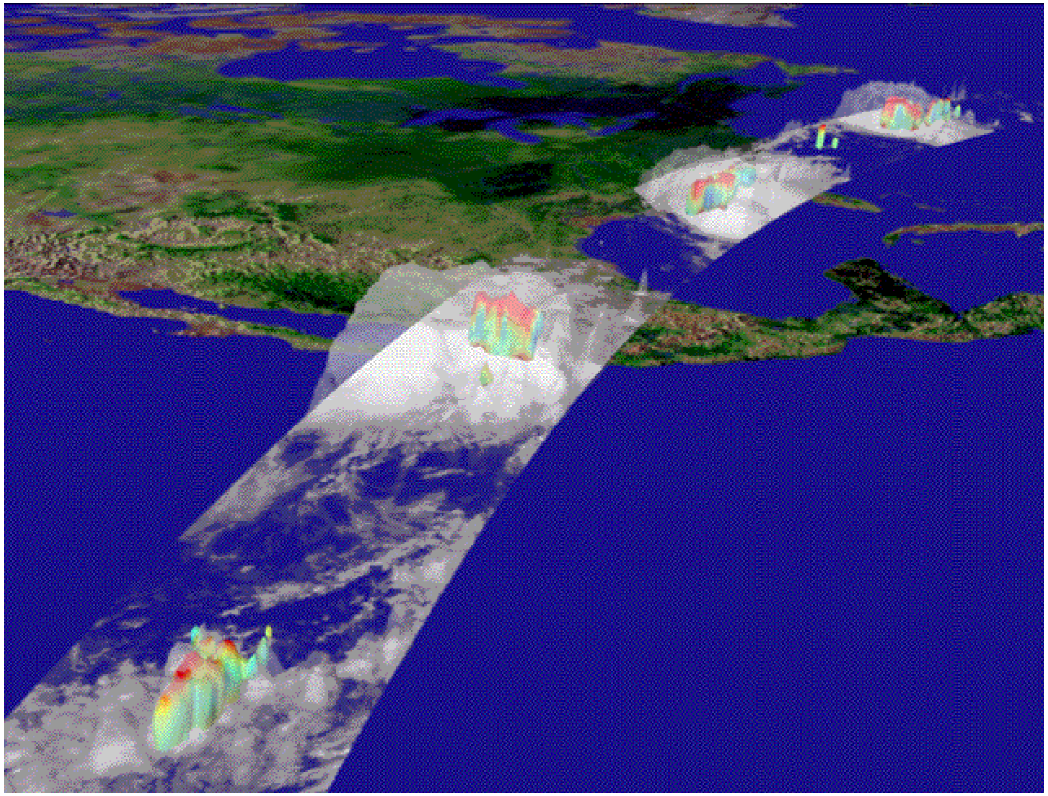
Introduction

- **OVERVIEW:**
  - The operational goal of this radar is to monitor the life cycle of the 3-D structure of hurricanes and convective storms from a Geostationary Orbit; this is accomplished by
    - Use of Ka-band frequency for high spatial resolution
    - Use of very large, scanning, deployable reflector antenna
    - Real-time processing to produce 3-D hurricane structures once per hour (to be compared with LEO radar coverage of once per day or less often)

- **SCIENCE:**
  - Time monitoring of dynamics of mesoscale precipitating cloud systems
  - Vertical profiling of precipitation and latent heat flux statistics
  - Provide detailed inputs to GCMs for global climate studies and inter-annual variations
  - Data synergy with GOES to get cloud thickness and cloud base information

- **APPLICATIONS (ULTIMATE GOAL):**
  - Provide unprecedented rain profiling data for NWP models for weather forecasting
  - Timely observation of natural hazards: hurricanes, flash floods
    - More accurate hurricane track and landfall prediction several days in advance
      - Provide sufficient time for advanced warning and evacuation (or not) planning

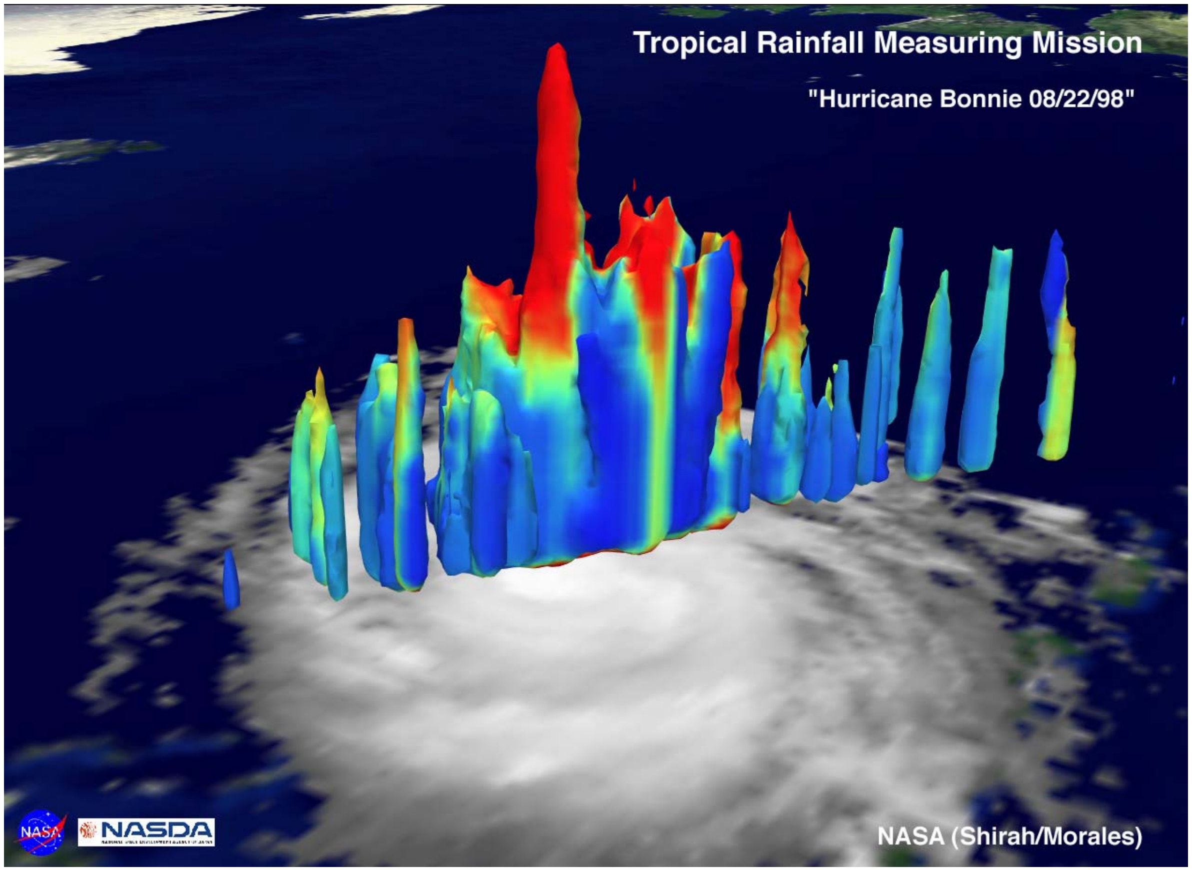
TRMM Precipitation Radar - The Pioneer



Tropical Storm Howard, Hurricane Isis, Hurricane Earl and Hurricane Danielle all line up under TRMM, passing over the scene from West to East on Sept. 2, 1998. (Courtesy of NASA/NASDA TRMM Project).

- TRMM satellite's primary rain sensing instruments
  - Precipitation radar
  - Multi-frequency radiometer
- TRMM orbit
  - ±35° inclination
  - 350 km altitude (now 400 km)
- TRMM Radar characteristics
  - 14-GHz
  - 2-m antenna
  - Cross-track ±17° scanning
  - Reflectivity-only measurements
- TRMM instruments have made significant observations
  - Climate research
  - Weather prediction
  - Hurricane studies

Radar Advantages



- Penetrate all precipitating and non-precipitating clouds relative to standard GOES cloud imagery
- Characterize hurricane structure and center of circulation even in the presence of upper-level clouds
- Enable 3-dimensional profiling of critical parameters and dynamics which control and/or determine the hurricane formation and evolution
  - Rain intensity
  - Vertical motion
  - Cloud process
  - Latent heat release
- Provide such data for NWPs for improved forecast and understanding of hurricane and storm dynamics

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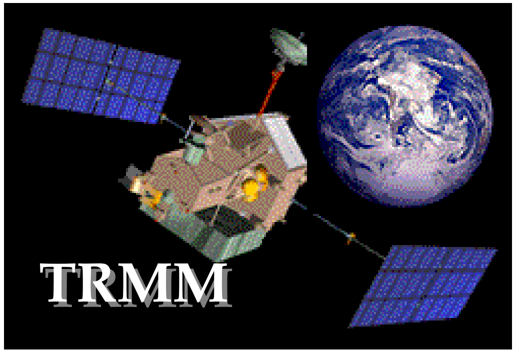
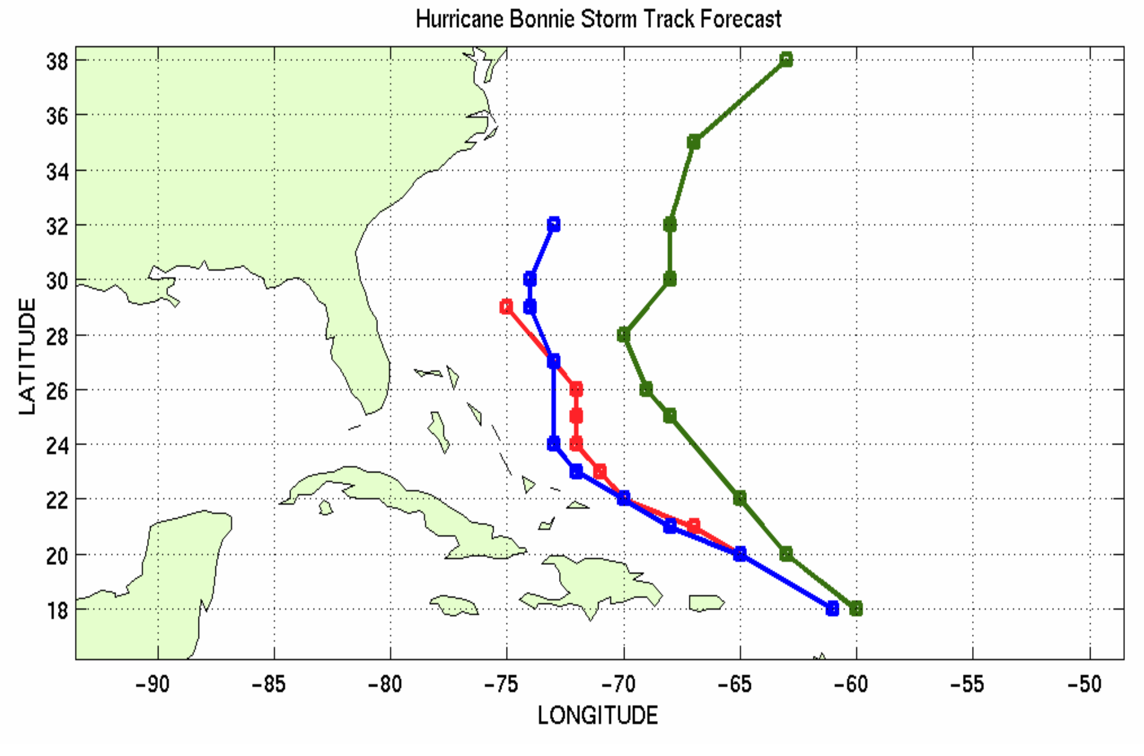
Hurricane Track Prediction Improvement

Assimilation of TRMM precipitation data in global models

- Improves climate analysis
- Improves storm track forecast
- Improves precipitation forecast





5 day forecast of Bonnie storm track from 08/20/98

Red: best track (NOAA HRD)

Green: forecast from analysis without TRMM data

Blue: forecast from analysis with TRMM data

Instrument Concept and Innovations

- Monitoring time evolution of rain & cloud from GEO (alt. = 36,000 km)
- 35-GHz, 4˚ spiral scanning radar to cover 5300-km diameter earth disk (equivalent to coverage of 48˚ latitude and 48˚ longitude)
- Deployable circular aperture antenna to obtain 12 to 14 km horizontal resolution
- Innovative antenna scan strategy:
  - Spiral feed path with 1 transmit feed and 1 receive feed with fixed spacing to compensate for pulse delay
  - Scan by motion of 2 feeds on spiral path
    - Advantage over 2-D electronic scan, which requires millions of phase shifters
    - Advantage over mechanical rotation of entire antenna, which creates unacceptable torque
    - Advantage over S/C rotation, which requires custom-made, usually very expensive S/C
- Vertical resolution of 300 m using pulse compression
- Rain detection sensitivity: ~ 5 dBZ (after 100 sample averaging)
  - ~12 dB more sensitive than the TRMM radar
- Vertical Doppler profile measurements with 0.3 m/s precision
- One 3-D full-scan image once per hour
- Real-time processing to reduce downlink data volume

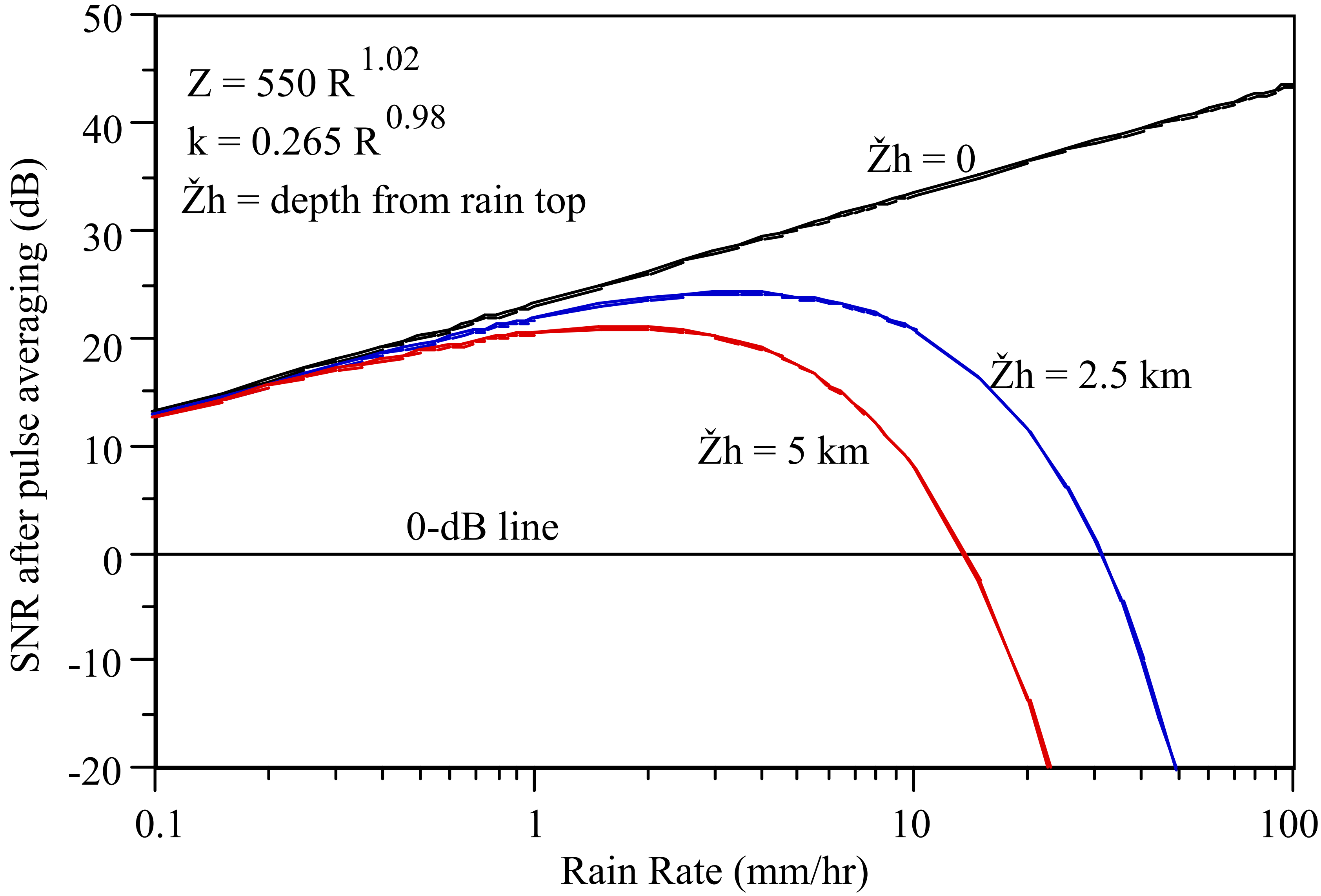
Design Considerations

- 35 GHz provides reasonable compromise between horizontal resolution and atmospheric attenuation.
- Maximum off-nadir look angle of 4 degrees results in 28 degree incidence angle relative to the surface. At larger angles surface clutter becomes more severe.
- A 4 degree max look angle, divided by 0.02 degree antenna beamwidth, implies 200 spirals for contiguous coverage; thus, feed must also travel on path with 200 spirals.
- Antenna considerations dictate a spiral path for the feed with radius of about 1.3 m.
- Coverage time of a few hours or less is desired for time sampling of mesoscale convective systems, including hurricanes.
- For complete spiral in one hour, feed must revolve around axis at constant linear speed of roughly 20 cm/s.
- Round trip time is approximately 0.25 sec; this requires a separate transmit and receive feed.
- To get good sensitivity and good range resolution, pulse compression is used with appropriate shaping of transmit pulse to minimize range sidelobes.
- Vertical resolution of 300 m is chosen as tradeoff between range resolution and sensitivity.

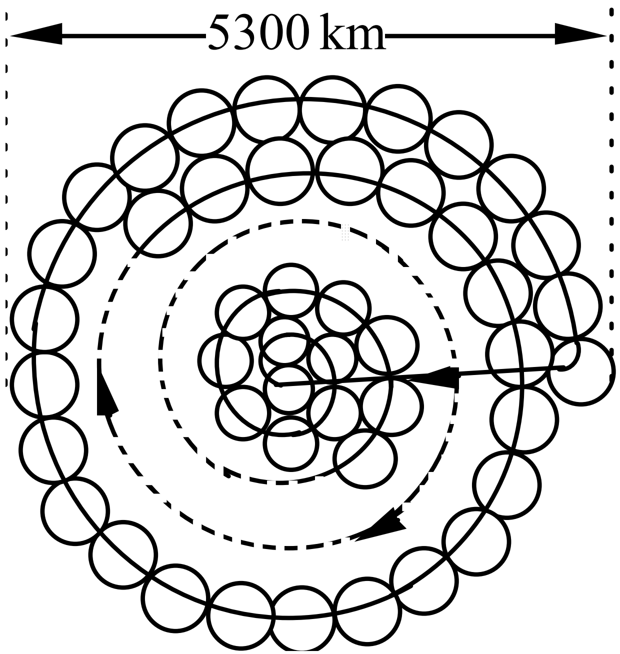
Preliminary Radar Parameter Design

Radar System Parameters			
Frequency	35 GHz	Bandwidth	0.58 MHz
Antenna diameter	30 m	Pulsewidth	100 µsec
Ant. effective aperture	28 m	PRF	3.5 KHz
Ant. 3-dB beamwidth	0.019Þ	Power duty cycle	35%
Antenna gain	77.2 dBi	Transmit path losses	2 dB
Antenna sidelobe	-30 dB	Receive path losses	2 dB
Max. spiral scan angle	4Þ	Sys. noise temp.	910 K
Time for a full scan	60 mins.	Dynamic range	70 dB
Peak power	100 W	Downlink data rate	155 kbps
Performance Parameters			
Disk coverage diameter	5300 km	Doppler Precision	0.3 m/s
Vertical resolution	300 m	Pulse samples	120
Horiz. Resolution (nadir)	12 km	Min. Zeq (1 pulse)	15.4 dBZ
Horiz. Resoution (4Þ)	14 km	Min. Zeq (after ave.)	5.0 dBZ

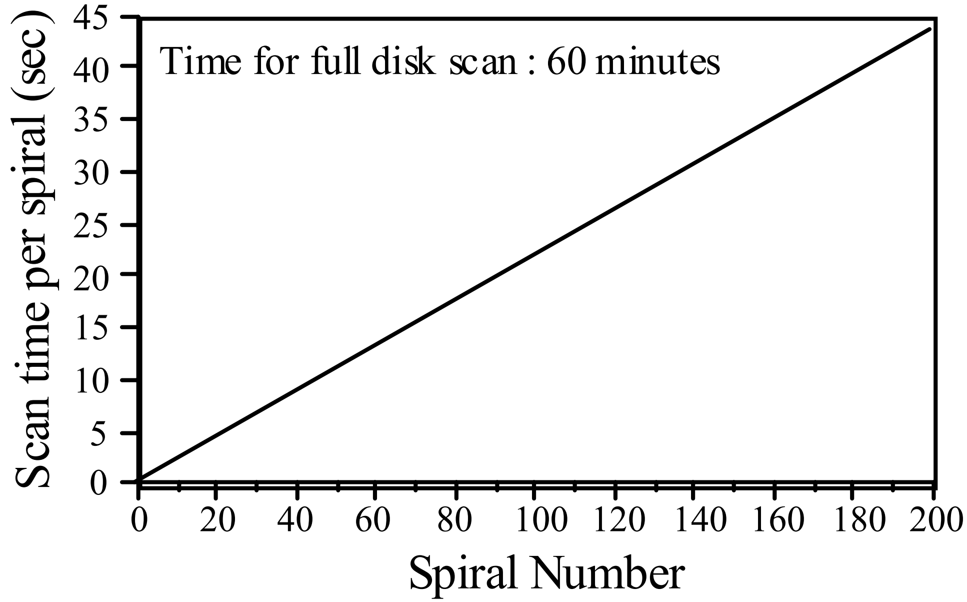
Signal-to-Noise Ratios



Spiral Scan Pattern / Rate

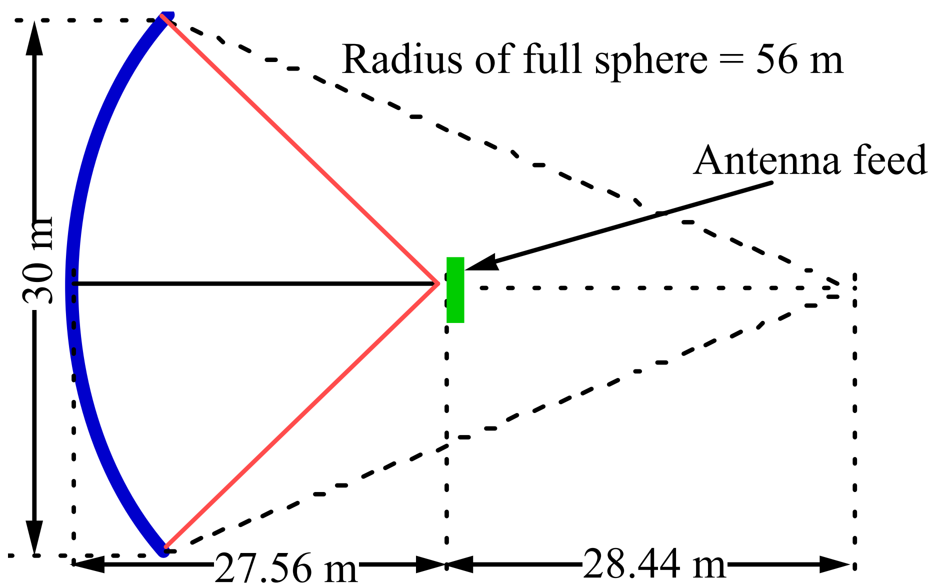


Ground pattern

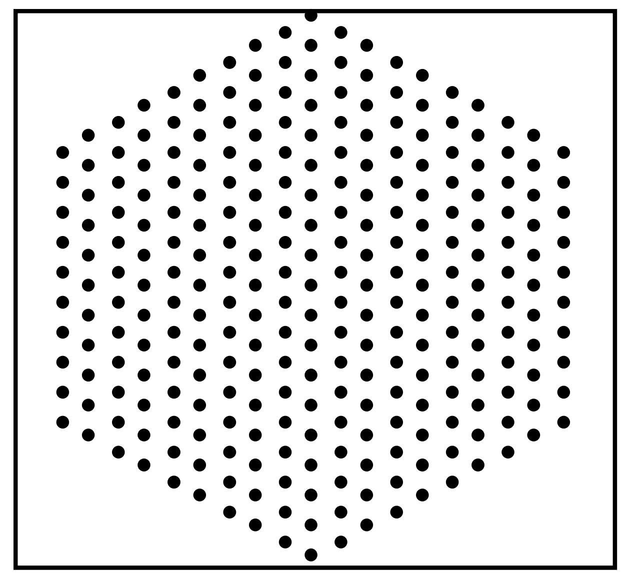


Antenna Design

- Spherical antenna reflector allows 2-dimensional scan with minimum degradation
- 271 array feeds to ensure excellent gain and sidelobe performance; the phase distribution over the array feed is designed to compensate for spherical aberration.
- 28 m aperture, larger physical size to allow for scanning (30-35 m), F/D of ~ 1

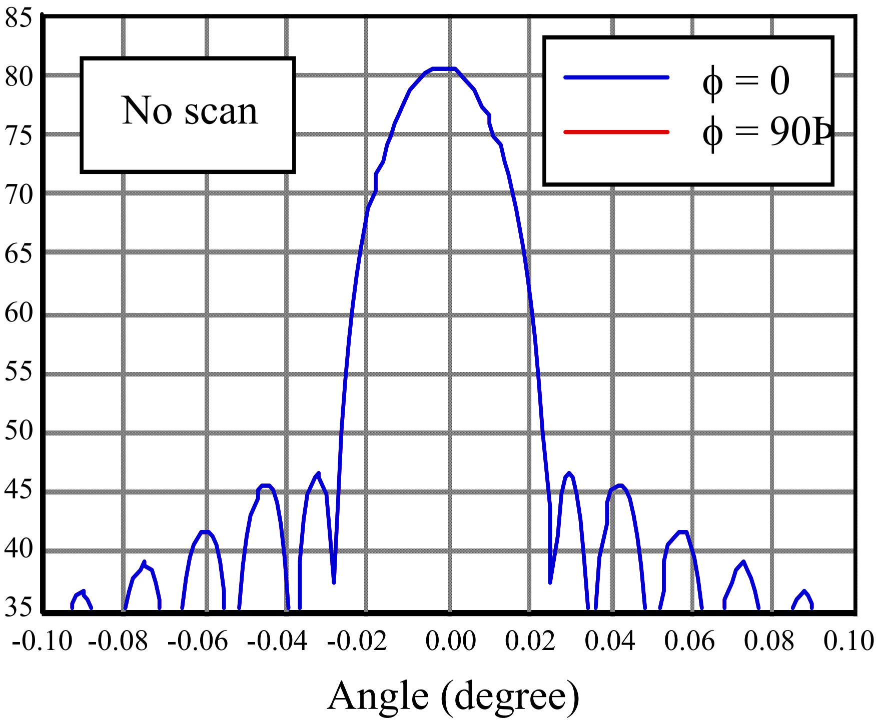


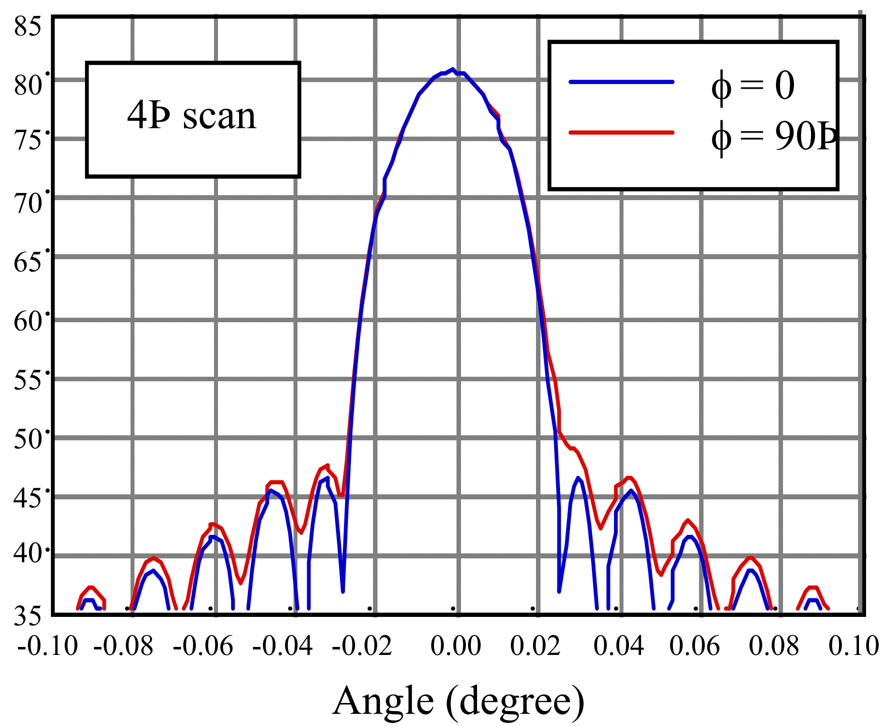
Spherical reflector



271-element feed array

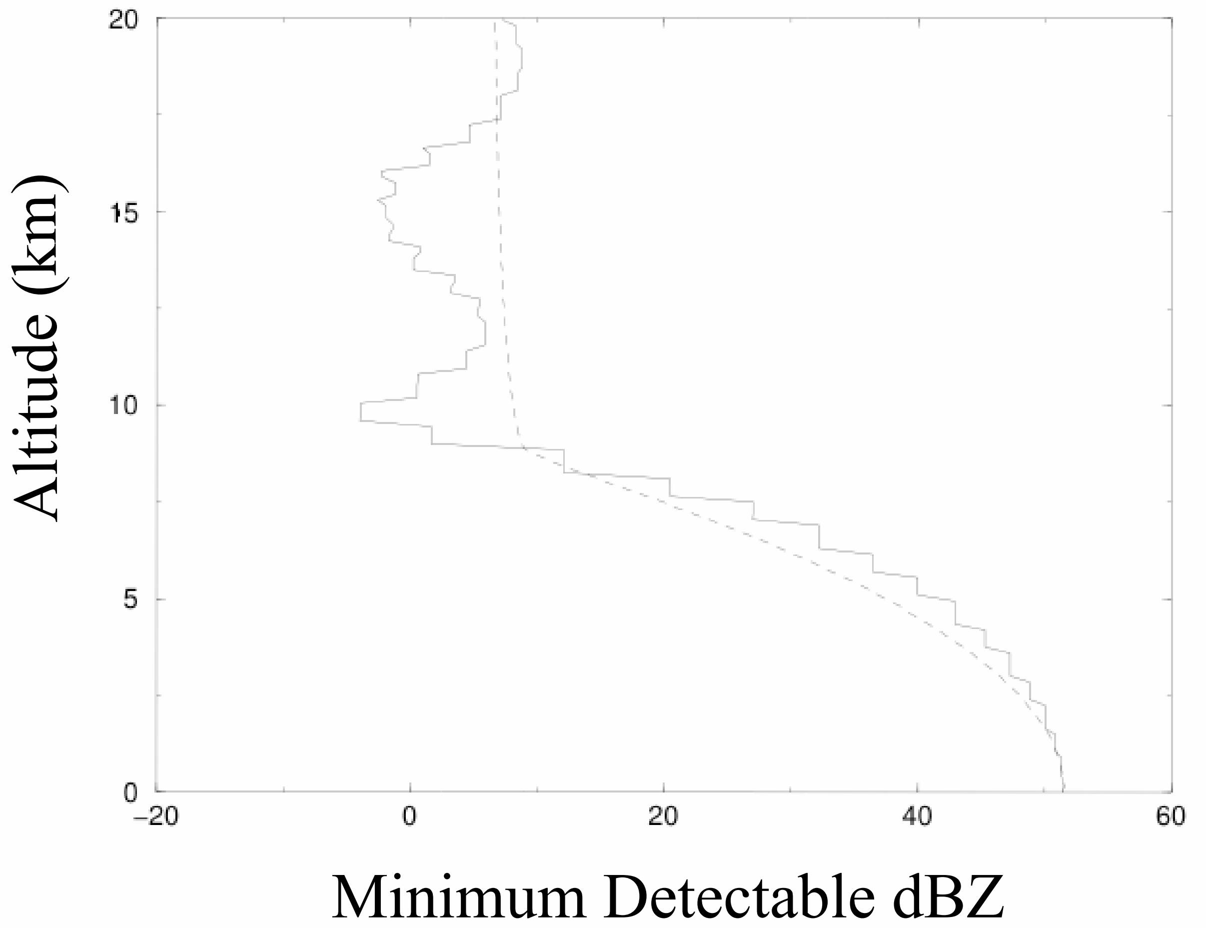
Calculated Antenna Patterns



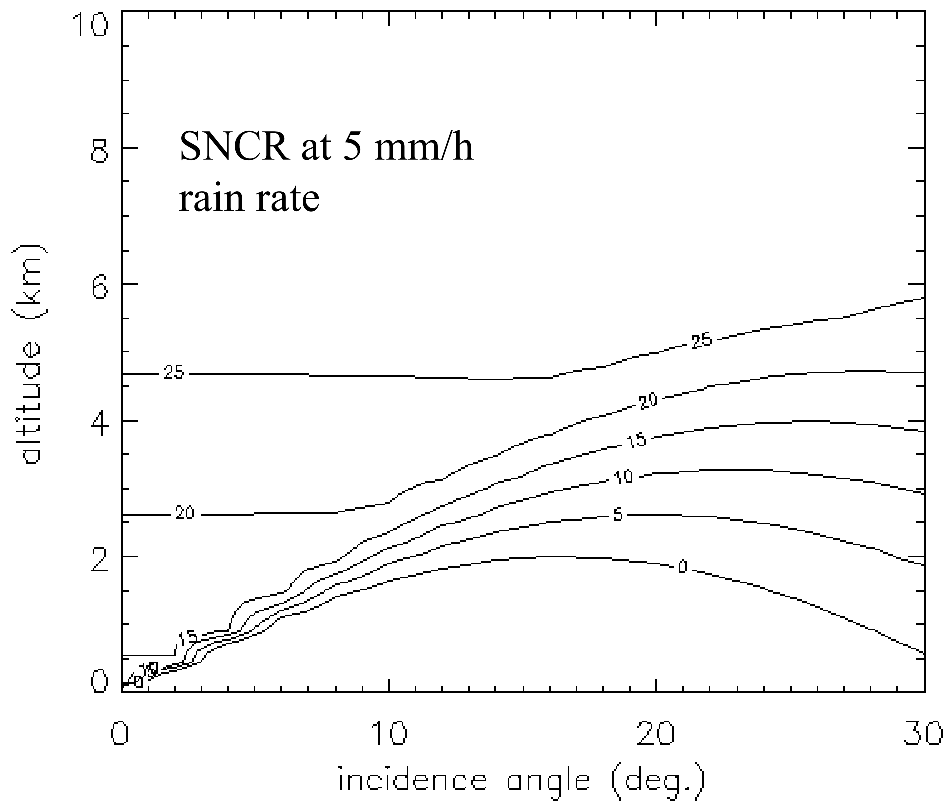


Clutter vs. Altitude for 271 Element Feed

- Clutter at 4 degrees off-nadir angle using spherical reflector with correction is similar to that using ideal pattern
- In rain, surface clutter is reduce by attenuation, not included here



Signal-to-Noise-and-Clutter Ratio (SNCR)



- Similar to all downward pointing atmospheric radars, NIS return signals from light rain can be contaminated by the simultaneous surface returns when the antenna is scanned away from nadir.
- At or near nadir the SNCR is dominated by thermal noise.
- Between ~5° and 15° incidence angles and at lower altitudes, the surface clutter becomes dominant.
- At larger incidence angles the clutter effect is reduced due to increased attenuation and weaker surface backscattering
- Conclusions:
  - The results thus show that at 5 mm/hr rain NIS can indeed penetrate down to lower than 2 km altitude at most incidence angles of interest.
  - At larger rain rates the detectability is primarily determined by attenuation and thermal noise, not clutter.
  - Doppler filtering may be used to further reduce clutter.

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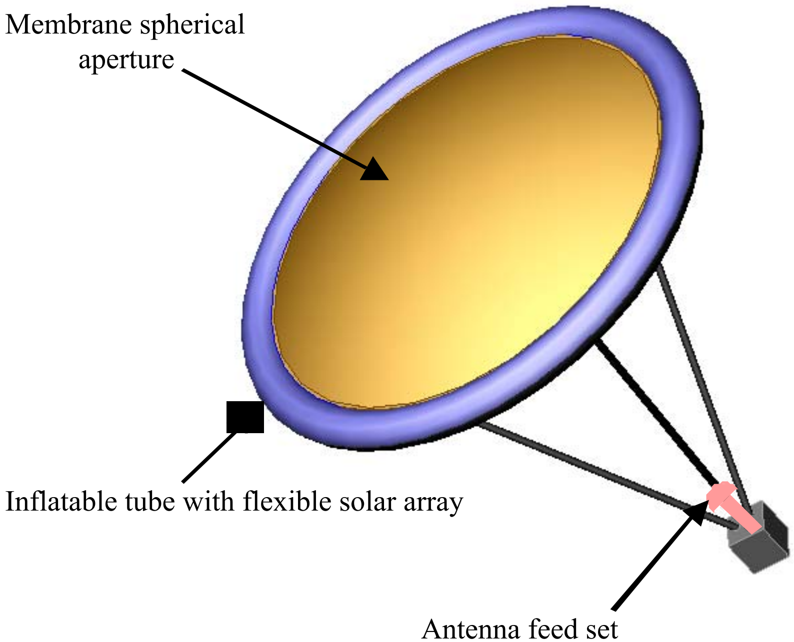
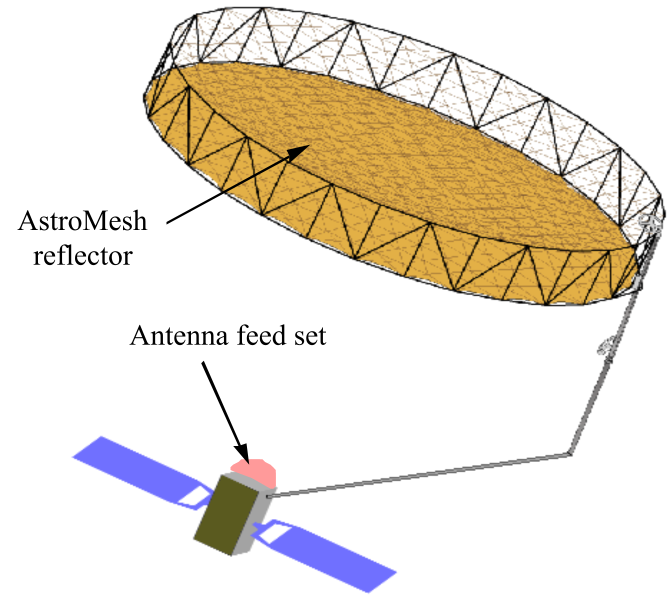
Mesh vs. Membrane Antenna Reflector Technology Options



(1) Membrane



(2) Mesh

(3) Hybrid: uses the mesh to deploy a reflective thin-film antenna aperture

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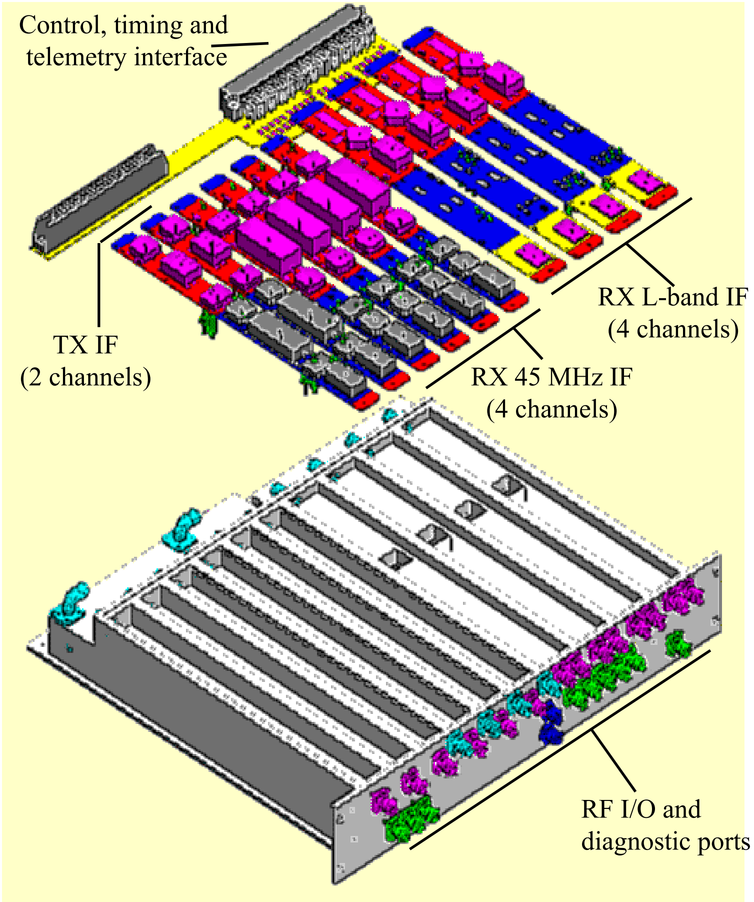
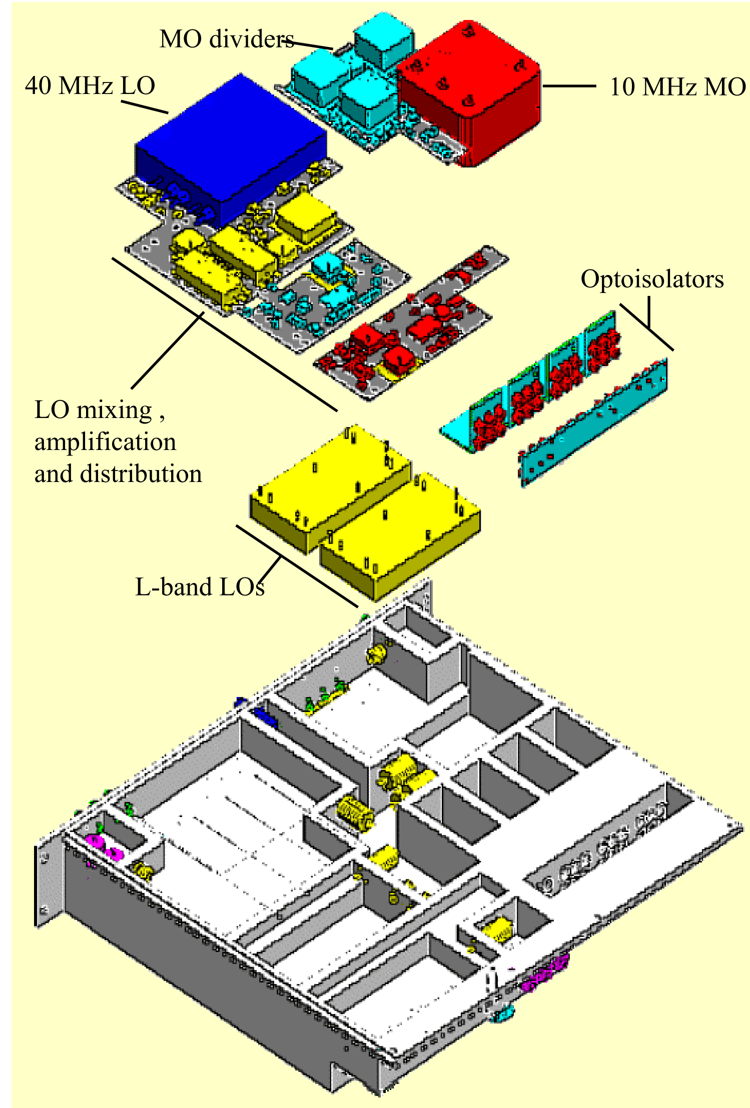
NIS RF Electronics Technology Leverages off ESTO PR-2 Development





- Contains all RF components operating below 10 GHz
  - Two (2) transmitter IF channels (14 H, 35 H)
  - Four (4) receiver IF channels (14 H/V, 35 H/V)
- Compact (size of 2 VME cards)
- Conduction cooling

Signals upconverted to L-band at spacecraft, upconverted to Ka-band at feed array

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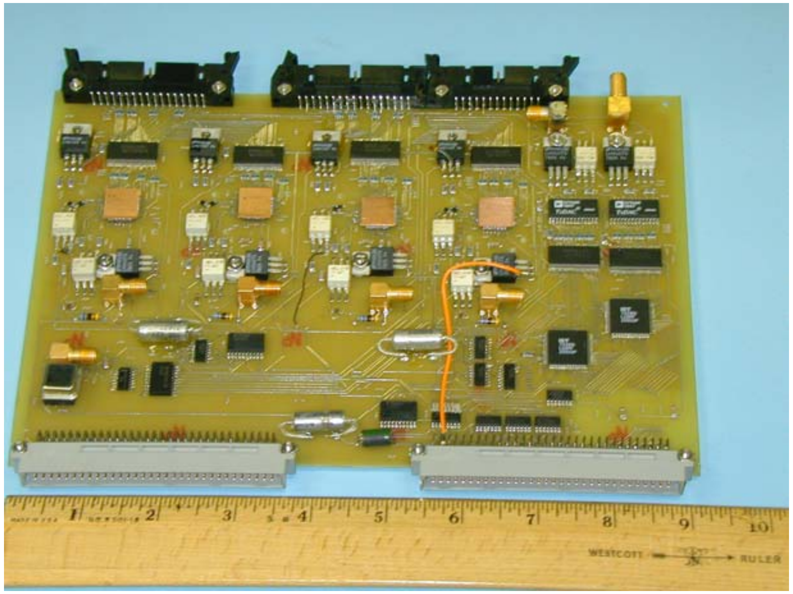
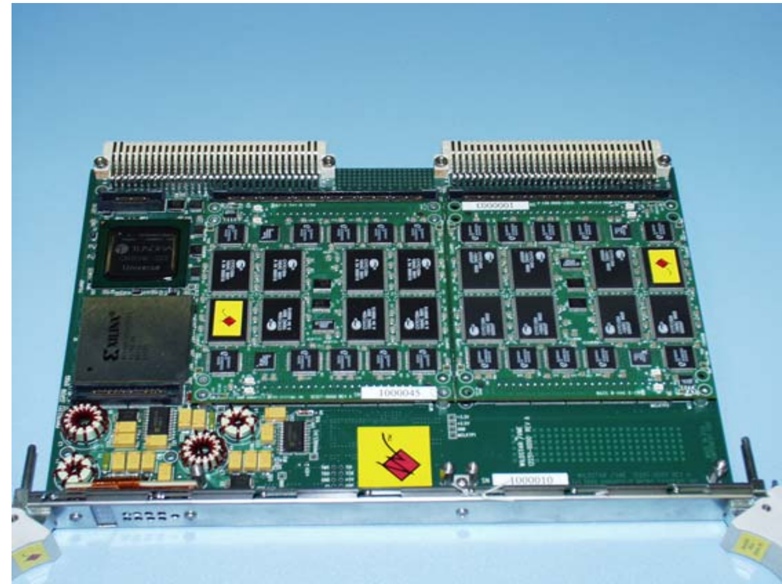
Digital Electronics Technology Leverages off ESTO PR-2 Development



- ADC/AWG
  - 12- bit ADC and Variable Waveform (AWG) Generator cluster.
  - ADC oversamples 2 times for improved sample filtering
  - AWG includes pre-distortion function to reduce pulse compression sidelobe



- FPGA-based Data Processor
  - Real-time processing
    - Adaptive scan
    - Pulse compression
    - Pulse/Doppler processing
  - Double buffer
  - Computer power:
    - 20 billion multiplications
    - 20 billion additions

Summary

- Geostationary radar offers a major advantage over radars in other orbits in that weather systems can be sampled at intervals of hours rather than days.
- The large range from radar to earth requires a very large antenna.
- Our approach to scanning the antenna is to use a fixed spherical reflector with scanning provided by motion of a transmit/receive feed set.
- Ordinarily, a spherical reflector would have poor performance in such areas as gain and sidelobes, due to spherical aberration.
- The approach being used here implements both feeds as arrays, with phase distributions designed to correct for spherical aberration
  - Numerical calculations have shown that the correction reduces sidelobes to the required levels.
- The systems design is still preliminary; various studies (e.g., mechanical scan approach, clutter reduction) are being carried out.
- Additionally, we are beginning development of a 1.5 m bread board model of the antenna to demonstrate the spherical correction technique. The F/D ratio is chosen as 0.4 so that the breadboard will have the same degree of correction as the full-size.
- The mechanical scan mechanism will also be bread boarded.